Evaluation of New Jersey Route 18 OPAC/MIST Traffic-Control System

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Conventional traffic-control strategies have limitations in handling unanticipated traffic demands. An adaptive traffic-signal control is expected to mitigate this problem and improve overall system performance. Furthermore, with the increasing needs of evolving intelligent transportation systems, traffic signals are expected to provide significantly greater functionalities, which can be achieved only by adaptive control. A product of many years of development, Optimized Policies for Adaptive Control (OPAC) represents a significant step forward in adaptive signal-control research. The OPAC strategy was field-tested at a New Jersey site. The performance of OPAC was compared against a well-designed time-of-day signal control. The evaluation was performed under various traffic-demand conditions and included both isolated intersections and arterial sections. The analysis indicated a highly significant improvement with OPAC control. OPAC showed its best performance during oversaturated conditions. It reduced the travel time and number of stops by about 26 percent and 55 percent, respectively, for the entire arterial section. OPAC also improved traffic performance during changing demand conditions. It significantly improved the performance of an isolated intersection during undersaturated traffic conditions. OPAC reduced stopped delay on the major-street approach by 40 percent without affecting the minor-street performance.

Optimized Policies for Adaptive Control (OPAC) is a real-time traffic-adaptive signal-control strategy. A product of more than 12 years of development, OPAC continually underwent verification and validation tests. Although some field tests were conducted on an earlier version of OPAC, the evaluation efforts mostly were restricted to laboratory tests using simulation.

In the spring of 1996, the OPAC signal-control strategy was field-tested under various test conditions at a site on New Jersey Route 18 consisting of 15 OPAC-controlled intersections (Figure 1). The study section is a north-south arterial street with two-way traffic operation, covering 17 km of the roadway in New Brunswick.

The field test was conducted to evaluate the effectiveness of the OPAC algorithm under various traffic-demand levels as well as two different signal-control types: isolated and arterial. Conventional time-of-day (TOD) signal control was used as the benchmark condition for making the comparison. This paper reports the results obtained from the field evaluation.

BACKGROUND

OPAC has undergone evolution since it was first developed by Gartner (*1*). The first version of OPAC, designated OPAC-1, used a dynamic programming approach, which is a mathematical optimization of multistage decision processes. The subsequent version, OPAC-2, was a simplification of the OPAC-1 algorithm. A rolling horizon concept was later introduced in the algorithm. This concept is used mainly by operations research analysts in production-inventory control. The algorithm was renamed ROPAC. At this point the algorithm was still an off-line program. The ROPAC program was reorganized for implementation in real time and called OPAC-RT Version 1.0. This version was restricted to two-phase operation. Version 2.0 could simulate eight-phase timing but could control only the four major (through) phases. These two versions were field-tested at three isolated intersection sites (*2*). The field results indicated that OPAC performed better than fully actuated signals, especially at higher demand levels.

Version 3.0 of OPAC-RT incorporated several enhancements that are important for efficient operation and that make the algorithm workable for situations other than isolated intersections. Enhancements included optimization of all eight phases, phase skipping, dynamic speed calculations, and a platoon identification and modeling algorithm that provides a coordination mechanism for adjacent signals. The New Jersey implementation of Version 3.0 provided the necessary site for its evaluation.

SITE DESCRIPTION

The Route 18 OPAC system has been implemented in MIST, a traffic-management software system, and is operated from an unmanned computer facility. The field system can operate in both TOD and OPAC modes of signal control. The system normally operates in the OPAC mode of control. If TOD is required, control is synchronized by a separate closed-loop system.

Figure 2 illustrates the configuration of the controllers and vehicle sensors at the Route 18 site. Multisonics 820A NEMA controllers are connected to the signals and sensors. The OPAC prototype is installed on the open architecture controller (OAC), referred to in this paper as the OPAC controller. When the OPAC mode is activated, the OPAC controller controls the signals by passing commands to the NEMA controller. The OPAC controller also is connected to additional sensors (referred to as the OPAC sensors), which provide the upstream traffic information required by OPAC.

STUDY PROCEDURE

In this study, comparisons of traffic performance were made between the control and the trial conditions. *Control condition* refers to the conventional signal control in which all 15 signals were switched to TOD control. This condition is represented by a coordinated arterial control consisting of semiactuated signals. The signal-timing plans were developed using state-of-the-art techniques, including

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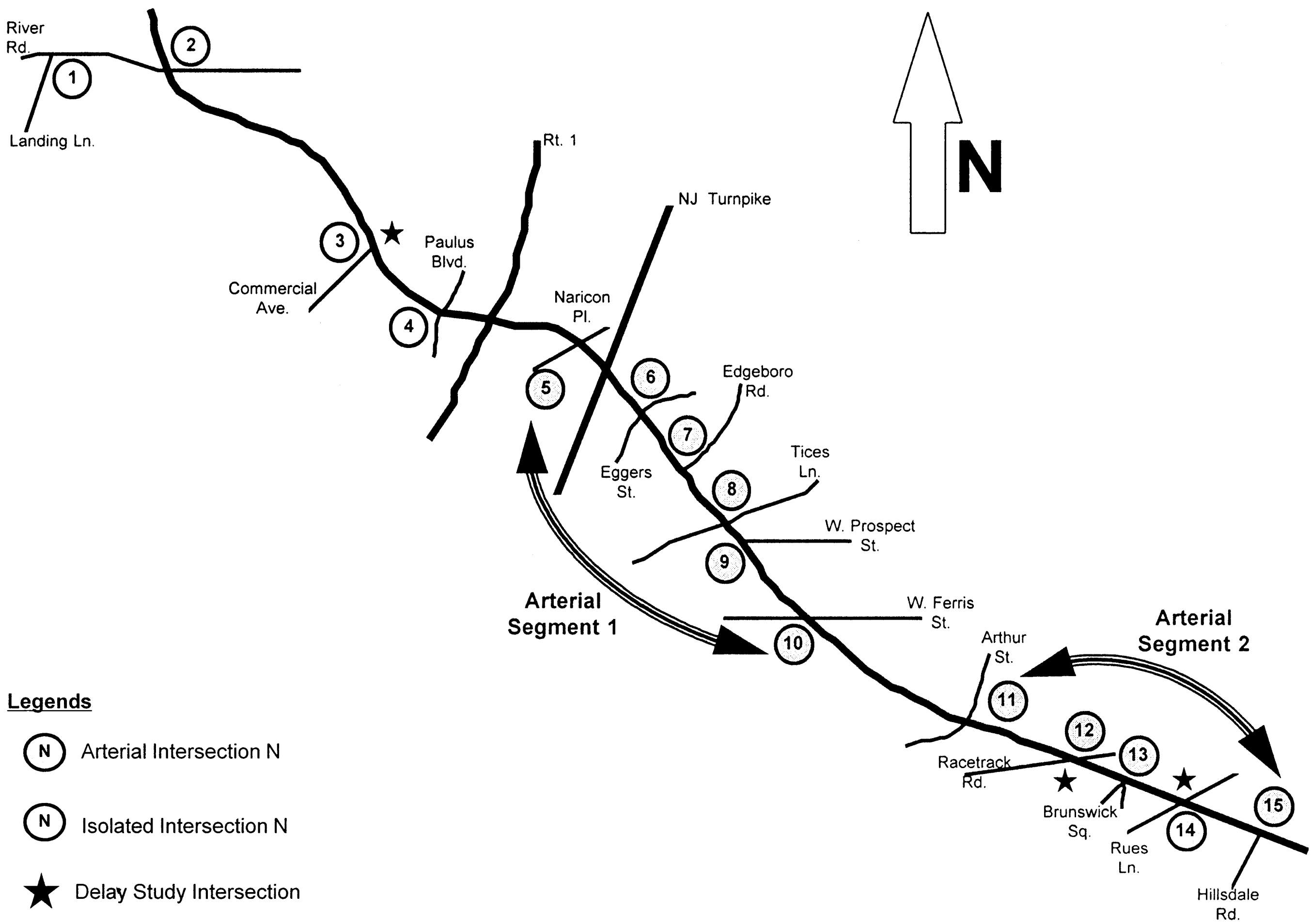

FIGURE 1 Study road section.

optimizing signal-timing parameters by time of day using the PASSER II software application. *Trial condition* refers to traffic control using OPAC strategies. Under this condition, all 15 signals were in the OPAC mode of operation.

Test Conditions

The test was conducted to evaluate the performance of OPAC under various conditions. For signal control, the test covered the following conditions:

- Open arterial. The arterial section (Route 18 between Hillsdale Road and Naricon Place) was selected to test this condition. Separate statistics were generated for the entire section as well as its two segments. Travel-time and throughput data were collected to evaluate the performance of OPAC along Route 18. Two sample arterial intersections (Racetrack Road and Rues Lane) were selected for delay studies to evaluate the side-street performance.
- Isolated intersection. The intersection of Route 18 and Commercial Avenue was selected for performing intersection delay studies.

For traffic demand, selected test conditions were (*a*) heavy demand (a.m. and p.m. peaks), (*b*) changing demand (post–p.m. peak), and (*c*) light demand (early morning)

Test Schedule

The historic traffic-volume information contained in the MIST data base was used to determine appropriate schedules for the field test. A 3-week field data-collection plan (including 1 week for contingency) was developed. The schedule allowed 1 week each for the TOD and OPAC controls. Monday morning and Friday afternoon were avoided because of the possible bias resulting from the weekend. Most field data collection was scheduled to occur within the representative weekdays—Tuesday through Thursday. The period 6:45 a.m. to 8:00 a.m. on weekdays was used for the a.m. peak study and 4:00 p.m. to 6:45 p.m. was used for the p.m. peak study. The period 8:00 p.m. to 10:00 p.m. on week nights was selected for evaluating OPAC under changing traffic-demand conditions. Weekday early mornings (4:00 a.m. to 6:00 a.m.) were selected for conducting the field test under low-demand conditions. An off-peak period, 10:00 a.m. to 12:45 p.m., during weekdays was selected for testing the isolated intersection.

Data-Collection Methods

Table 1 lists the methods used for collecting specific data. The *Manual of Traffic Engineering Studies* (*3*) was used as a general guide for this study. The survey was aided significantly by available automated tools. The various studies conducted are discussed as follows:

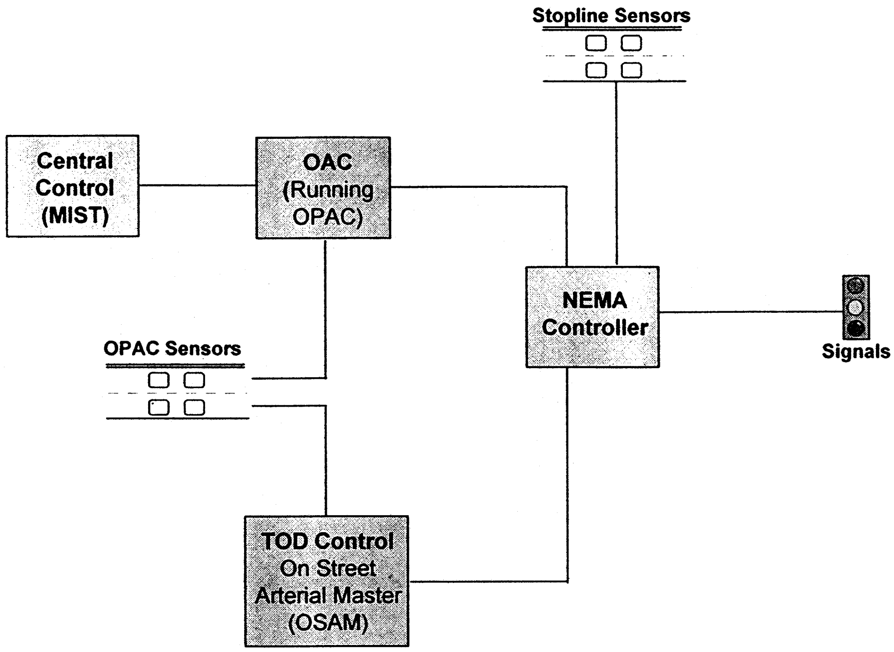

FIGURE 2 Controller and sensor configuration in the Route 18 system.

- Delay studies. Delay studies were conducted at the isolated intersection and the selected intersections belonging to the arterial section. The measures of effectiveness (MOEs) collected were stopped delay and percent of vehicles stopped. Custom laptop software was used to collect stopped delay data. Stops and total volume were manually recorded.
- Travel-time studies. Travel-time studies were conducted along the Route 18 arterial section. The MOEs observed were travel time and number of stops per trip. The test-car technique was used, which involved driving a vehicle with the traffic stream for determining the travel time. The vehicle was driven according to the driver's judgment of the average speed of the traffic stream. Three vehicles were used in the data-collection process, which was significantly aided by automated data-collection devices. Connected to the car's transmission, the devices calculated the speed data and stored them in a portable computer.
- Throughput and demand analysis. Throughput was used as a MOE to measure the efficiency of the arterial section and its two segments. Throughput, in this context, refers to the downstream traffic volume exiting the system, while demand refers to the upstream traffic volume entering the system. Traffic-demand data were used to establish consistency between the control and trial MOEs. Both throughput and demand data were downloaded from the central computer data base, collected by OPAC sensors, and stored by the MIST system.

TABLE 1 Data-Collection Methods

Data Item	Data Collection Method
Travel time - Entire arterial section - By segment	Vehicles using automated travel-time data-collection devices connected to laptop computers.
Stops during travel - No. of stops - Stopped time delay	Vehicles using automated travel-time data-collection devices connected to laptop computers.
Intersection statistics (for both isolated intersection and arterial side streets) - Stopped delays - Percent of vehicles stopped	Collection of vehicle count data manually using field data sheets. Collection of delay data using software application running on laptop computer.
Link traffic volumes (demand)	OPAC detectors/MIST data base
Traffic volume throughput - Entire arterial section - By segment	OPAC detectors/MIST data base

Analysis Methods

The raw data were compiled and analyzed with a spreadsheet application. The field data were examined to ensure that only good data were used in the analysis. Analysis of variance (ANOVA) and *t*-tests were used to analyze the MOE data for comparing performances between the control and trial conditions. Traffic-demand data also were compared statistically to ensure consistency between the control and trial conditions. All statistical tests were conducted at level $\alpha = .05$, unless otherwise specified.

ARTERIAL SECTION ANALYSIS

The arterial section analysis included travel-time and throughput studies for the arterial section and intersection delay studies for the sample intersections. Individual statistics (travel time and stop per trip) were generated for the entire arterial section and its two segments. Analysis was performed for both north- and southbound directions for various traffic demand conditions. Table 2 presents the results of the travel-time studies.

Side-street MOE data (stopped delay and percent of vehicles stopped) were collected at two intersections during a.m. and p.m. peak conditions. These MOEs were calculated for time intervals of at least 7 min. The results of this analysis are summarized in Table 3.

As with the travel-time studies, the entire arterial section (between Hillsdale Road and Naricon Avenue) and its two segments were considered for analysis. The throughput data were measured for both

TABLE 2 Arterial Section Travel-Time Study, Control Versus Trial

Condition	Southbound Travel Time Segment 1	Segment 2	Overall	Southbound Stops Segment 1	Segment 2	Overall
Early Morning	NS	NS	NS	NS	NS	NS
a.m. Peak	NS	NS	NS	NS	NS	NS
p.m. Peak	Improved 37.4%	NS	Improved 25.6%	Improved 66.2%	NS	Improved 55.4%
Post- p.m. Peak	NS	Improved 5.8%	Improved 4.4%	NS	NS	NS

Condition	Northbound Travel Time Segment 1	Segment 2	Overall	Northbound Stops Segment 1	Segment 2	Overall
Early Morning	NS	NS	NS	NS	NS	NS
a.m. Peak	NS	NS	NS	NS	NS	NS
p.m. Peak	NS	Degraded 12.6%	NS	Improved 19.2%	Degraded 38.8	NS
Post- p.m. Peak	NS	Improved 13.6%	Improved 6.9%	NS	NS	NS

***NOTE:* The following notations are used in Tables 2 through 7:**

NS: Not statistically significant
NS[a]: Statistically significant difference in throughput, which resulted from the respective difference in demands
NS[b]: The test was significant at level $\alpha = .05$, but not significant at $\alpha = .04$
Improved: Performance improvement is statistically significant
Degraded: Performance degradation is statistically significant
SIG: Statistically significant

north- and southbound directions. The results of the throughput analysis are presented in Table 4.

An examination of the results reveals that there was no evidence of improved travel-time/stops or throughput during the light-demand (early-morning) period. For moderately saturated demand (a.m. peak), the results yield the following observations:

- No improvement was achieved in travel time/stops or throughput during the a.m. peak on the arterial.
- The side-street delay study at the intersection of Route 18 and Racetrack Road did not show any effect from the use of OPAC.
- The side-street delay study at the intersection of Route 18 and Rues Lane indicated a 22 percent increase in stopped delay per vehicle for the eastbound approach (with no change in percent of vehicles stopped). The westbound approach did not show any effect from the use of OPAC.

For heavy demand (p.m. peak), the following were observed:

- OPAC showed its best performance during oversaturated conditions on the southbound arterial section. The study indicated that OPAC reduced the travel time by 37 percent for the most congested northern segment (Segment 1) and 27 percent for the entire arterial. Similarly, it reduced the vehicle stops per trip by 66 percent for Segment 1 and 55 percent for the entire arterial.
- In the southbound direction, throughput for Segment 1 increased by 7 percent, but there was no significant change in throughput for the overall arterial section. No change was observed in the northbound direction.
- Some side-street approaches experienced higher delay and percent of vehicles stopped. Stopped delay increased by a maximum of 39 percent, while percent of vehicles stopped increased by as high as 9 percent.
- Although OPAC improved the southbound traffic operation significantly, it caused some degradation to the northbound travel time and the side-street MOEs. However, the northbound traffic is the noncritical direction of flow and the side streets carry low traffic volume compared to Route 18 traffic. Therefore, the degradation is considered relatively minor. The improvement outweighs the degradation, representing an overall system improvement during the p.m. peak period.
- The northern arterial segment (Segment 1) received the most significant improvements. Coincidentally, this segment is much more congested than the southern segment and includes interchanges with two major traffic sources: U.S. Route 1 and the New Jersey Turnpike.

For changing demand (post–p.m. peak), the following observations were made:

- OPAC improved the traffic performance satisfactorily in both directions of the arterial for the post–p.m. peak period (steadily decreasing traffic-demand condition). Travel time decreased by up to 7 percent for the entire section and a maximum of 14 percent for an arterial segment. A decrease in traffic throughput was attributed to the decrease in respective traffic demand.
- The demand level gradually decreased during the 2-hr period. One test objective was to examine whether the demand level had any impact on the effectiveness of traffic control (irrespective of OPAC or TOD). The analysis did not reveal any significant changes in the effectiveness of traffic control with decreasing demand levels.

ISOLATED INTERSECTION ANALYSIS

The intersection of Route 18 and Commercial Avenue was selected for testing OPAC at an isolated intersection during the off-peak period 10:00 a.m. to 12:45 p.m. Stopped-delay and percent-of-vehicles-stopped data were collected for the eastbound Commercial Avenue

TABLE 3 Arterial Side-Street Intersection Delay Study, Control Versus Trial

Time	MOE	Racetrack Road Eastbound	Racetrack Road Westbound	Rues Lane Eastbound	Rues Lane Westbound
a.m. Peak	Delay	NS	NS	Degraded 21.5%	NS
	% of Stops	NS	NS	NS	NS
p.m. Peak	Delay	Degraded 39.4%	Degraded 28.4%	Degraded 22.5%	NS
	% of Stops	NS	Degraded 5.0%	Degraded 9.3%	NS

TABLE 4 Throughput Analysis, Control Versus Trial

	Northbound		Southbound	
Time	Overall*/ Segment 1	Segment 2	Overall**/ Segment 2	Segment 1
Early Morning	NS	NS	NS	NS
a.m. Peak	NS	NS	NS	NS
p.m. Peak	NS	NS	NS	Improved 7.0%
Post–p.m. Peak	NS[a]	NS[a]	NS[a]	NS

*For northbound direction, overall system throughput and Segment 1 throughput are measured at the same roadway section
**For southbound direction, overall system throughput and Segment 2 throughput are measured at the same roadway section

and southbound Route 18 approaches. These two approaches represent the critical traffic movements that govern the phase durations during this off-peak period. The MOEs were calculated for time intervals of at least 7 min to represent each data point.

The results of analysis are presented in Table 5. Analysis indicates highly significant reduction (39.7 percent) in stopped delay for the major street approach (southbound Route 18), without affecting the performance of the minor street approach (eastbound Commercial Avenue). No significant effect was observed for percent of vehicles stopped at either approach.

The data were used to calculate the stopped delay and percent of vehicles stopped for the southbound and eastbound approaches combined. The calculation indicated that an overall 21.2 percent reduction in stopped delay was achieved with OPAC control.

The traffic demand conditions also were recorded as part of the percent-of-vehicles-stopped calculation. A *t*-test indicated no significant difference in traffic demand between the control and trial conditions.

This test was conducted under moderate traffic demand. Therefore, the test results for the isolated intersection represent an undersaturated traffic demand condition.

DEMAND ANALYSIS

The demand analysis was conducted to examine whether the traffic conditions remained the same during the test days for the arterial section analysis. Traffic-volume data were collected upstream of both ends of the arterial section to calculate demand in both northbound and southbound directions. There were traffic sources and sinks between the two ends of the arterial section. As such, the demands at the selected sections did not remain constant over the entire section and represented only the traffic demands on both ends of the arterial. However, the analysis provided a means for comparison of traffic demands among the test days.

The system-sensor data stored in the MIST data base were used for this purpose. The 15-min MIST data were converted to 30-min data to eliminate noise. The data then were compared by using ANOVA techniques to examine any differences among study days. Since the studies along the arterial were not necessarily conducted on the same days as the side-street studies, demand data were compared separately for the two cases.

Table 6 and 7 summarize the results of the demand analysis. There was no significant difference in traffic demands for the p.m. peak study, which yielded the most conclusive results pertaining to the performance of OPAC.

Statistically significant differences in traffic demand conditions occurred during a few study periods, however, which necessitated further interpretation of respective arterial-section analysis results. The variation in demand may or may not affect the collected MOEs substantially, depending on the specific MOE and the level of saturation. For example, travel time and intersection delay are not very sensitive to the demand at a low level of saturation, yet become highly sensitive at a near-saturation condition. On the other hand, traffic throughput is very sensitive to traffic demand at a low level of saturation because vehicles entering the system will tend to leave the system at the same rate. In an oversaturated condition, the throughput loses its sensitivity to the demand because it cannot exceed the system capacity. The effects of observed statistical differences in demands, therefore were analyzed accordingly.

The results of the demand analysis for the travel time and throughput studies are presented in Table 6. Significant differences in traffic demands are observed in both directions during the a.m. peak and post–p.m. peak. Individual cases of statistically significant differences were selected and discussions of the possible effects of differences in demand conditions are provided as follows:

- A.M. Peak, Northbound and Southbound. The statistical differences were marginal cases. At a slightly higher level of significance ($\alpha = .04$), the tests yielded nonconclusive results. Moreover, the difference in demand conditions were very low (the mean OPAC demands were about 4 percent lower than the mean TOD demands for both northbound and southbound cases). In view of these facts, the demand levels were considered to be consistent for the evaluation. No significant statistical results were obtained for the a.m. peak from the throughput and travel-time studies. As such, no interpretation of results is necessary.

TABLE 5 Isolated Intersection Delay Study, Control Versus Trial

		Southbound Approach		Eastbound Approach	
MOE		TOD	OPAC	TOD	OPAC
Stopped Delay	Mean, sec	7.59	4.72	34.18	35.39
	Significance*	Improved 39.7%			NS
% of Stops	Mean, %	31.7	31.2	73.65	77.80
	Significance*		NS		NS

*Statistically significant difference

TABLE 6 Demand Analysis for Travel-Time and Throughput Studies, Control Versus Trial

Time Period	Northbound	Southbound
Early Morning	NS	NS
a.m. Peak	NS[b]	NS[b]
p.m. Peak	NS	NS
Post–p.m. peak	SIG	SIG

TABLE 7 Demand Analysis for Side-Street Studies, Control Versus Trial

Time Period	Intersection	Northbound	Southbound
a.m. Peak	Rues Ln. at Rt. 18	NS	NS
	Racetrack Rd. at Rt. 18	SIG	NS
p.m. Peak	Rues Ln. at Rt. 18	NS	NS
	Racetrack Rd. at Rt. 18	NS	NS

- Post–p.m. Peak, Northbound. The mean demands during the OPAC and TOD test periods were 781 and 884 vehicles per hour (vph), respectively (i.e., the OPAC demand was 11.7 percent lower than the TOD demand). Although the percent difference in demand appears to be substantial, the related saturation level was very low (v/s and v/c ratios were 0.16 and 0.22, where *v*, *s*, and *c* denote volume, saturation flowrate, and capacity, respectively). In such undersaturated conditions, the difference in demand should not affect the travel-time and stops data. Observed improvements in northbound travel time therefore can be attributed to the OPAC control strategy. However, the demand differences were expected to affect the throughput values because traffic throughput is highly sensitive to demand at a low saturation level. The northbound throughput study results, therefore, require interpretation. The analysis indicated a decrease in northbound throughput with OPAC. Given the volume levels, this decrease should be attributed not to OPAC but to the decrease in demand.
- Post–p.m. Peak, Southbound. The mean demands during the OPAC and TOD test periods were 2,159 and 2,283 vph, respectively (i.e., the OPAC demand was 5.4 percent lower than the TOD demand). Since percent difference in demand was low and the related saturation level was moderate (v/s and v/c ratios were 0.40 and 0.57, respectively), the difference in demand should not significantly affect the travel-time and stops data. Observed improvements in southbound travel time therefore can be attributed to OPAC. However, the demand differences were expected to affect the throughput values. The southbound throughput study results, therefore, require interpretation. The analysis indicated a decrease in southbound throughput with OPAC. Given the volume levels, this decrease should be attributed to the decrease in respective demand.

The results of demand analysis for side-street intersection studies are presented in Table 7. Significant differences in traffic demands were observed during the a.m. peak at the intersection of Racetrack Road at Route 18. However, no conclusive statistical results were obtained from the study at this intersection during the a.m. peak. Hence, the difference in demand does not affect any analysis results.

These discussions indicate that the statistical difference in demand did not have any effect on the arterial travel-time and side-street-delay studies. However, it affected the conclusive results obtained from the post–p.m. peak throughput analysis and the results were interpreted accordingly in the throughput analysis.

CONCLUSIONS

A comprehensive evaluation was conducted to cover a number of signal-control and traffic-demand scenarios. As a result, the study yielded valuable insights about the performance of OPAC under various conditions. The study also yielded information that can be used for further enhancement of the OPAC algorithm, to make it more effective and versatile.

The study indicated that OPAC is most effective during highly oversaturated conditions and changing demand conditions for an arterial. OPAC also proved to be highly effective during undersaturated conditions at the isolated intersection. However, further evaluation is necessary for the testing of OPAC at isolated intersections under high demands.

Moreover, OPAC did not degrade system performance under any condition (except minor degradation of side-street delay during the a.m. peak). The results are promising for future implementations of OPAC.

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